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(54) Title: TRANSFORMATION STRUCTURES FOR APPROXIMATING COLOR MATCHING FUNCTIONS

(57) Abstract: RGB filter set (520) and color estimation performance for RGB LED color sensing (500) is provided. A criteria function describing an error between desired color matching functions and a spectral response of an RGB filter set (520) is constructed. RGB filter set (520) response characteristics based on the criteria function are then determined. Finally, color estimation parameters for substantially optimal color estimation (500) with the RGB filter set (520) are determined based upon the determined RGB filter set (520) response characteristics. Computer readable code for constructing a criteria function is provided. Computer readable code for determining RGB filter set (520) response characteristics is also provided. Finally, computer readable code for determining color estimation parameters is provided.

TRANSFORMATION STRUCTURES FOR APPROXIMATING
COLOR MATCHING FUNCTIONS

The invention relates to methods of color sensing and estimation. More particularly the invention relates to techniques for determining RGB filter set and color estimation

5 performance for RGB LED color sensing.

In the field of color sensing it is known that any instrument or process used to distinguish or sense colors as the human eye does must have spectral responses which correspond to some linear transformation of the CIE color mixture functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$. In color photography this condition is known as the Luther-Ives

10 condition. There are infinitely many real coefficients a_1, a_2 and a_3, such that $C(\lambda) = a_1 \bar{x}(\lambda) + a_2 \bar{y}(\lambda) + a_3 \bar{z}(\lambda)$, represents an equivalent new color matching function $C(\lambda)$. All functions of the $C(\lambda)$ family are equivalent under matrix transformation.

There is much greater freedom when using color filters for color sensing to approximately realize $C(\lambda)$ for a set of coefficients instead of physically realizing the CIE

15 color matching functions. Since there are infinitely many equivalent $C(\lambda)$'s, an appropriate set of $C(\lambda)$'s must be determined for a given color filter set.

In order to be approximated by practical color filters, the new transformed color matching functions need to satisfy three conditions: 1) $C(\lambda)$ is positive or zero throughout the entire spectral range; 2) $C(\lambda)$ has a single peak; 3) the overlaps between the three $C(\lambda)$'s are

20 as small as possible.

One transformation matrix satisfying the above conditions is the well known MacAdam's matrix given by:

$$Mc = \begin{pmatrix} 0.5115 & 0.5985 & -0.11 \\ -0.5081 & 1.4093 & 0.0988 \\ 0 & 0 & 1 \end{pmatrix}$$

The MacAdam's matrix satisfies the conditions for color matching functions that may be realized by real filters and is therefore of use in the design of filter sets for specific color sensing applications. Custom designed filters sets are particularly expensive to implement, especially when the filter must be designed in a specialized shape. For many applications of

5   color sensing, the custom designed filters necessary for optimal estimation are too expensive. It would be desirable to provide a method of utilizing existing low cost filters for sub-optimal color sensing to overcome these and other limitations.

The present invention is directed to a system and method for determining RGB filter set and color estimation performance for RGB LED color sensing. Color filter performance

10   for an RGB LED color sensing system is substantially optimized by determining transformation parameters to optimize spectral approximation. A calibration is provided to allow adjustment of parameters.

In accordance with the invention, a method for determining RGB filter set and color estimation performance for RGB LED color sensing is provided. Means for constructing a

15   criteria function describing an error between desired color matching functions and a spectral response of an RGB filter set are provided. Means for determining RGB filter set response characteristics based on the criteria function are also provided. Finally, means for determining color estimation parameters for substantially optimal color estimation with the RGB filter set based upon the determined RGB filter set response characteristics are

20   provided.

In accordance with another aspect of the invention a computer readable medium storing a computer program is provided. Computer readable code for constructing a criteria function describing an error between desired color matching functions and a spectral response of an RGB filter set is provided. Computer readable code for determining RGB filter set

25   response characteristics based on the criteria function is also provided. Finally, computer readable code for determining color estimation parameters for substantially optimal color estimation with the RGB filter set based upon the determined RGB filter set response characteristics is provided.

The foregoing and other features and advantages of the invention are apparent from

30   the following detailed description of exemplary embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

FIG. 1 shows the CIE color mixture function and the MacAdam's color matching functions;

FIG. 2 is a flow diagram illustrating a method for determining RGB filter set and color estimation performance for RGB LED color sensing;

5   FIG. 3 shows a flow diagram illustrating a process for determining color estimation parameters for RGB LED color sensing;

FIG. 4 is a block diagram illustrating an exemplary computer system that may be used to implement the method of the invention; and

FIG. 5 is a block diagram of an exemplary RGB color sensing and estimation system

10   to which the invention may be applied.

The present invention is directed to a system and method for determining RGB filter set and color estimation performance for RGB LED color sensing. FIG.1 contains spectral response plots of the CIE color matching functions, $\overline{x}(\lambda)$ 120 , $\overline{y}(\lambda)$ 130, and $\overline{z}(\lambda)$ 140, and corresponding color matching functions $\overline{xmc}(\lambda)$ 150 , $\overline{ymc}(\lambda)$ 160, and $\overline{zmc}(\lambda)$ derived

15   from the MacAdam's matrix. Note that the function $\overline{zmc}(\lambda)$, while present, is not visible on FIG.1 as $\overline{z}(\lambda)$ matches $\overline{zmc}(\lambda)$. FIG. 1 is provided for illustration and will be recognized by those skilled in the art.

A criteria function describing an error between desired color matching functions and a spectral response of an RGB filter set is constructed. RGB filter set response characteristics

20   based on the criteria function are then determined. Finally, color estimation parameters for substantially optimal color estimation with the RGB filter set are determined based upon the determined RGB filter set response characteristics. Additional steps not elucidated may occur within the following description and some steps may be combined, omitted or occur in a different order without departing from the spirit and scope of the invention.

25   FIG. 2 shows a flow diagram illustrating a process for determining RGB filter set and color estimation performance for RGB LED color sensing. Process 200 begins in step 210. A criteria function describing an error between desired color matching functions and the spectral response of an RGB filter set is constructed in step 210. The criteria function is a linear vector function bounded over a spectral bandwidth. In general, the criteria function

30   describes the performance of a color sensing or estimation system typically comprised of a set of color filters, a set of RGB LED illuminants and a set of color sensors. An advantage of the present invention is that the system color filters may be of the low-cost film variety. The

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criteria function includes a matrix of the spectral responses of red, green and blue LED's respectively, and an unknown constant correction vector "n" that is subtracted from the MacAdam's matrix functions and the RGB filter sensitivity functions with an unknown constant matrix "M." The criteria function therefore provides a means to determine system

5　filter performance through evaluation of the unknown constant vectors. If a computer implements step 210, a database may be automatically accessed to obtain various data to construct the criteria function such as the system RGB LED illuminant spectral data and the system filter spectral response data.

In step 220, RGB filter set response characteristics are determined based on the

10　criteria function. Response characteristics include constant terms for the vector "n" and the matrix "M." The criteria function is evaluated to determine values for "M" and "n." In one embodiment, the criteria function is a constraint set criteria function with a minimum value constraint. In the present discussion, the minimum value of the criteria function with constraint set "M" and "n" is a color filter performance index for the system RGB LED

15　illuminants. Therefore, the scalar values of "M" and "n" that result in a minimum value criteria function determine the system color filter performance.

In step, 230 color estimation parameters for substantially optimal color estimation with the RGB filter set are determined based upon the system RGB filter set response characteristics determined in step 210. Step 230, occurs at any time after the determination of

20　"n" and "M" in step 220. Step 230 comprises one or more color estimation parameter determinations. In one embodiment, color estimation parameters includes structures describing localized spectral approximations with weighting functions. In another embodiment, color estimation parameters includes structures describing a new set of estimated tristimulus values of a white light illuminant formed by an RGB LED set. In yet

25　another embodiment, color estimation parameters includes structures describing a color calibration for a color estimation system. Substantially optimal color estimation is sub-optimal estimation that approaches the ideal of the CIE color mixture functions or a linear combination equivalent, while remaining sub-optimal. The color estimation parameters determined in step 230 provide inverse transformation structures that allow substantially

30　optimal color sensing and estimation with low-cost color filters. The criteria function J is generally represented by an equation in the form:

$$\underset{M,n}{J} = \int_\sigma \left| \begin{bmatrix} R_{LED}(\lambda) & 0 & 0 \\ 0 & G_{LED}(\lambda) & 0 \\ 0 & 0 & B_{LED}(\lambda) \end{bmatrix} \begin{bmatrix} \overline{xmc}(\lambda) \\ \overline{ymc}(\lambda) \\ \overline{zmc}(\lambda) \end{bmatrix} - M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} - n \right| d\lambda, \qquad (1)$$

where $r(\lambda)$, $g(\lambda)$ and $b(\lambda)$ are positive real continuous sensitivity functions of the RGB

filter set and $\lambda \in \sigma = [380, 780]$ nm, $R_{LED}(\lambda)$, $G_{LED}(\lambda)$ and $B_{LED}(\lambda)$ are the spectra of red,

green and blue LED light sources respectively and where

$\overline{xmc}(\lambda), \overline{ymc}(\lambda), and\ \overline{zmc}(\lambda)$ are a set of color matching functions, and M is a 3x3 constant

matrix and n is a 3x1 constant vector.

If a computer implements step **230**, a database may be automatically accessed to

obtain various data to determine color estimation parameters.

FIG. 3 shows a flow diagram illustrating a process for determining color estimation

parameters for RGB LED color sensing as in step **230** of FIG. 2. Process **230** begins in step

340. In step **340**, spectral approximation functions $\hat{x}$, $\hat{y}$, and $\hat{z}$ for the RGB LED light

sources are constructed from the "M" and "n" determined by evaluating the criteria function.

The spectral approximation functions include a weighting function. The spectral

approximation functions are represented by an equation in the form:

$$\begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = (M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} + n)^* u\{M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} + n\}, \qquad (2)$$

where u is a unit step function.

In step **350**, estimated tristimulus values are determined based on the spectral

functions estimated in step **340**. The system color sensors equipped with the system color

filter set estimate the new tristimulus values based on the white light emission of the system

RGB LED's. The estimated tristimulus values $\hat{X}$, $\hat{Y}$, $\hat{Z}$ are determined according to the

relationship represented by the equation:

$$\begin{bmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix} = \int_\sigma \begin{bmatrix} \hat{x}(\lambda) \\ \hat{y}(\lambda) \\ \hat{z}(\lambda) \end{bmatrix} P(\lambda) d\lambda, \qquad (3)$$

where $P(\lambda) = R_{LED}(\lambda) + G_{LED}(\lambda) + B_{LED}(\lambda)$.

In step 360, a color sensing calibration is implemented. The calibration occurs after the determination of tristimulus values in step 360. A calibration matrix is determined and applied to correct for error in the system color estimation. The calibration is determined according to the relationship represented by the equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M_{cal} Mc^{-1} \begin{bmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix} \qquad (4)$$

where *X, Y and Z* are tristimulus functions of the RGB LED illuminants and where M_{cal} is a calibration matrix and Mc^{-1} is an inverse MacAdam's matrix.

FIG. 4 is a block diagram illustrating an exemplary computer system **400** that may be used to implement the method of the invention. FIG. 3 shows a computer system **400** containing: an I/O device **410**; a processor **420**; a user interface **430**; memory **440**; a display **450**; removable storage **460**; a bus **490**; and, mass storage **470** containing a database **475**, programs **476** and an operating system **477**. In FIG. 3 the I/O device **410**, the processor **420**, the user interface **430**, the memory **440**, the display **450**, the removable storage **460** and the mass storage **470** are all shown coupled to the bus **490**. The I/O device **410** is additionally shown enabled for communication external to computer system **400**.

The I/O device **410** is a device capable of bidirectional data communication with a device external to the computer system **300**. Examples of I/O devices include serial, parallel, USB, Ethernet and IEEE 802.11 compliant wireless devices, for example.

The processor **420** is a computing device usually containing memory and data control capability, such as caching and the like. The processor **420** may be integrated with supporting hardware such a video controller, a storage device controller and the like. The processor **420** generally executes instructions of a computer program such as program **476**, for example.

The user interface **430** is a device such as a keyboard, a mouse, a pointing device, a pen, a microphone or another device used to provide a data entry interface with a user of the computer system **400**.

The memory **440** is a hardware or virtual storage for computer code and data that the processor is manipulating. Memory **440** includes all dynamic memory external to the processor including video memory, additional cache memory and the like. Portions of mass storage **470** may also be used to provide virtual memory that may be used interchangeably with the memory **440**.

The display 450 is a visual display such as a CRT, LCD, plasma or projection display used to provide a user with a visual interface with the computer system 400.

The removable media 460 is any device that provides a removable medium for storing computer code or data such as a magnetic disc drive, a writable optical disc drive or the

5   equivalent.

The mass storage 470 is any device that provides storage for computer code and data such as a hard disk drive a recordable optical medium and the like. In one embodiment, the mass storage 470 is provided by a second computer server system over a network (not shown). The mass storage generally contains the operating system 477, programs 476 and

10   may include a database 475. Programs include applications for execution by the computer system 400.

The bus 490 is a bidirectional communication device that enabled data communication between the various devices of computer system 400. The bus may include a processor and other logic devices to enable multiple data clock speeds and protocols

15   depending upon the connected devices.

FIG. 5 is a block diagram of an exemplary RGB color sensing and estimation system 500 to which the invention may be applied. In FIG. 5 the color sensing system is comprised of an RGB LED illuminant 510, a color filter 520 and a color sensor 530. The RGB LED illuminant is generally comprised of a trio of a red, green and blue light emitting diodes. The

20   RGB LED's have tristimulus values X, Y and Z respectively. The color filter 520 is generally a trio of red, green and blue filters of the polycarbonate film variety and equivalents. The color sensor is generally a trio of red, green and blue color sensors. Typically, the color filter 520 is attached to the color sensor 530; however, it is not necessary for the operation of the color sensing system 500.

25   An example of the system and method of the invention in operation is now provided. However, the following illustration is merely an example of the manner in which the invention may be practiced and in no way describes all applications or cites all known embodiments of the invention.

A computer system, such as computer system 400 of FIG. 4, enabled to implement the

30   invention is configured to access a database containing low cost color filter and RGB LED data based on the manufacturer and product code and the like. A user provides other data concerning the color estimation system components, such as specific RGB LED units and color sensor units and the model number of the filter selections. The computer then accesses

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the filter data and constructs a criteria function. The computer then determines the filter set performance and provides values for "n" and "M." The computer then constructs approximated spectral response functions based on the determined "n" and "M." The computer then calculates estimated new tristimulus values for the approximated spectral

5 response functions. A color calibration matrix is then determined by the computer based upon the estimated tristimulus values and the actual tristimulus values for the system RGB LEDs as provided in the computers database. In this manner, a calibrated substantially optimal color estimator for an RGB LED illumination system is designed.

While the preferred embodiments of the invention have been shown and described,

10 numerous variations and alternative embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.

CLAIMS:

1.   A method for determining RGB filter set 520 and color estimation performance for RGB LED 510 color sensing 500, the method comprising:

constructing a criteria function 210 describing an error between desired color matching functions and a spectral response of an RGB filter set 520;

determining RGB filter set 520 response characteristics based on the criteria function 220; and

determining color estimation parameters for substantially optimal color estimation with the RGB filter set 520 based upon the determined RGB filter set 520 response characteristics 230.

2.   The method of claim 1 wherein determining the RGB filter 520 response characteristics comprises evaluating the criteria function to determine the RGB filter 520 response characteristics resulting in a minimum value of a constraint set criteria function.

3.   The method of claim 2 wherein the criteria function is represented by the equation:

$$\underset{M,n}{J} = \int_{\sigma} \left| \begin{bmatrix} R_{LED}(\lambda) & 0 & 0 \\ 0 & G_{LED}(\lambda) & 0 \\ 0 & 0 & B_{LED}(\lambda) \end{bmatrix} \begin{bmatrix} \overline{xmc}(\lambda) \\ \overline{ymc}(\lambda) \\ \overline{zmc}(\lambda) \end{bmatrix} - M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} - n \right| d\lambda$$

wherein $r(\lambda)$, $g(\lambda)$ and $b(\lambda)$ are positive real continuous sensitivity functions of the RGB filter set 520 wherein $\lambda \in \sigma = [380, 780]$ nm and wherein $R_{LED}(\lambda)$, $G_{LED}(\lambda)$ and $B_{LED}(\lambda)$ are the spectra of red, green and blue LED light sources 510 and wherein

$\overline{xmc}(\lambda), \overline{ymc}(\lambda), and \overline{zmc}(\lambda)$ are a set of color matching functions and wherein M is a 3x3 constant matrix and n is a 3x1 constant vector.

4.   The method of claim 3 further comprising:

constructing spectral approximation functions 340 $\hat{x}$, $\hat{y}$, and $\hat{z}$ for the RGB

LED light sources 510 from the M and n determined by evaluating the criteria function.

5.   The method of claim 4 wherein the spectral approximation functions are

represented by the equation:

$$\begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = (M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} + n) * u\{M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} + n\}$$ and wherein u is a step function.

6.   The method of claim 5 further comprising:

determining estimated tristimulus values 350 for the RGB LED light sources

510 based upon the spectral approximation functions.

7.   The method of claim 6 wherein the estimated tristimulus values $\hat{X}$, $\hat{Y}$, $\hat{Z}$ are

determined according to the relationship represented by the equation:

$$\begin{bmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix} = \int_{\sigma} \begin{bmatrix} \hat{x}(\lambda) \\ \hat{y}(\lambda) \\ \hat{z}(\lambda) \end{bmatrix} P(\lambda) d\lambda$$ wherein $P(\lambda) = R_{LED}(\lambda) + G_{LED}(\lambda) + B_{LED}(\lambda)$.

8.   The method of claim 7 further comprising:

implementing a color sensing color calibration 360 through the function represented by the equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M_{cal} Mc^{-1} \begin{bmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix}$$ wherein X, Y and Z are tristimulus functions of the RGB LED

illuminants 510 and wherein M_{cal} is a calibration matrix and wherein Mc^{-1} is an inverse MacAdam's matrix.

9.   A computer readable medium 460 storing a computer program 478 comprising:

computer readable code for constructing a criteria function 210 describing an error between desired color matching functions and a spectral response of an RGB filter set 520;

computer readable code for determining RGB filter set 520 response characteristics based on the criteria function 220; and

computer readable code for determining color estimation parameters for substantially optimal color estimation with the RGB filter set 520 based upon the determined RGB filter set 520 response characteristics 230.

10.   The computer readable medium 460 of claim 9 wherein determining the RGB filter 530 response characteristics comprises evaluating the criteria function to determine the RGB filter 520 response characteristics resulting in a minimum value of a constraint set criteria function.

11.   The computer readable medium **460** of claim 10 wherein the criteria function
is represented by the equation:

$$\underset{M,n}{J} = \int_{\sigma} \left| \begin{bmatrix} R_{LED}(\lambda) & 0 & 0 \\ 0 & G_{LED}(\lambda) & 0 \\ 0 & 0 & B_{LED}(\lambda) \end{bmatrix} \begin{bmatrix} \overline{xmc}(\lambda) \\ \overline{ymc}(\lambda) \\ \overline{zmc}(\lambda) \end{bmatrix} - M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} - n \right| d\lambda$$

wherein *r(λ)*, *g(λ)* and *b(λ)* are positive real continuous sensitivity functions of the RGB filter
set wherein $\lambda \in \sigma = [380, 780]$ nm and wherein $R_{LED}(\lambda)$, $G_{LED}(\lambda)$ and $B_{LED}(\lambda)$ are the
spectra of red, green and blue LED light sources **510** and
wherein $\overline{xmc}(\lambda), \overline{ymc}(\lambda), and \overline{zmc}(\lambda)$ are a set of color matching functions and wherein *M*
is a 3x3 constant matrix and *n* is a 3x1 constant vector.

12.   The computer readable medium **460** of claim 11 further comprising:
        computer readable code for constructing spectral approximation functions
$\hat{x}, \hat{y}, and \hat{z}$ for the RGB LED light sources **510** from the *M* and *n* determined by evaluating
the criteria function for the RGB filter set **520**.

13.   The computer readable medium **460** of claim 12 wherein the spectral
approximation function equation is:

$$\begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix} = (M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} + n) * u\{M \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} + n\}$$ wherein *u* is a step function.

14.   The computer readable medium **460** of claim 13 further comprising:
        computer readable code for determining estimated tristimulus values for the RGB
LED light sources **510** based upon the spectral approximation functions.

15. The computer readable medium **460** of claim 14 wherein the estimated tristimulus values $\hat{X}, \hat{Y}, \hat{Z}$ are determined according to the relationship represented by the equation:

$$\begin{bmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix} = \int_{\sigma} \begin{bmatrix} \hat{x}(\lambda) \\ \hat{y}(\lambda) \\ \hat{z}(\lambda) \end{bmatrix} P(\lambda)d\lambda \text{ wherein } P(\lambda) = R_{LED}(\lambda) + G_{LED}(\lambda) + B_{LED}(\lambda).$$

16. The computer readable medium **460** of claim 15 further comprising:

computer readable code for implementing a color sensing color calibration **360** through the function represented by the equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M_{cal}Mc^{-1} \begin{bmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix} \text{ wherein } X, \; Y \; and \; Z \text{ are tristimulus functions of the RGB LED}$$

illuminants **520** and wherein M_{cal} is a calibration matrix and wherein Mc^{-1} is an inverse MacAdam's matrix.

17. A system for determining RGB filter set **520** and color estimation performance for RGB LED color sensing **500** comprising:

means for constructing a criteria function describing an error between desired color matching functions and a spectral response of an RGB filter set **520**;

means for determining RGB filter set **520** response characteristics based on the criteria function; and

means for determining color estimation parameters for substantially optimal color estimation with the RGB filter set **520** based upon the determined RGB filter set **520** response characteristics.

18.   The system of claim 17 further comprising:

means for constructing spectral approximation functions $\hat{x}, \hat{y}$, and $\hat{z}$ for the RGB LED light sources 510 from the M and n determined by evaluating the criteria function.

19.   The system of claim 18 further comprising:

means for determining estimated tristimulus values for the RGB LED light sources 510 based upon the spectral approximation functions.

20.   The system of claim 19 further comprising:

means for implementing a color sensing color calibration through the function represented by the equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M_{cal} Mc^{-1} \begin{bmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{bmatrix}$$ wherein X, Y and Z are tristimulus functions of the RGB LED

illuminants 510 and wherein M_{cal} is a calibration matrix and wherein Mc^{-1} is an inverse MacAdam's matrix.
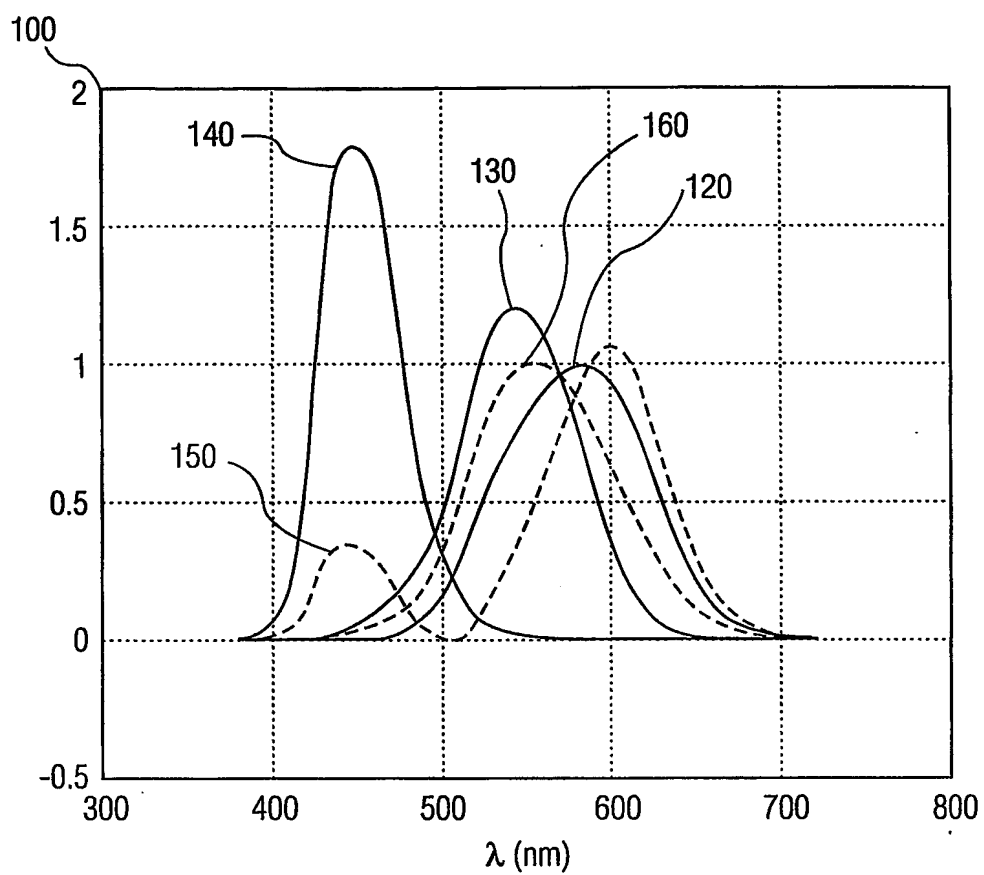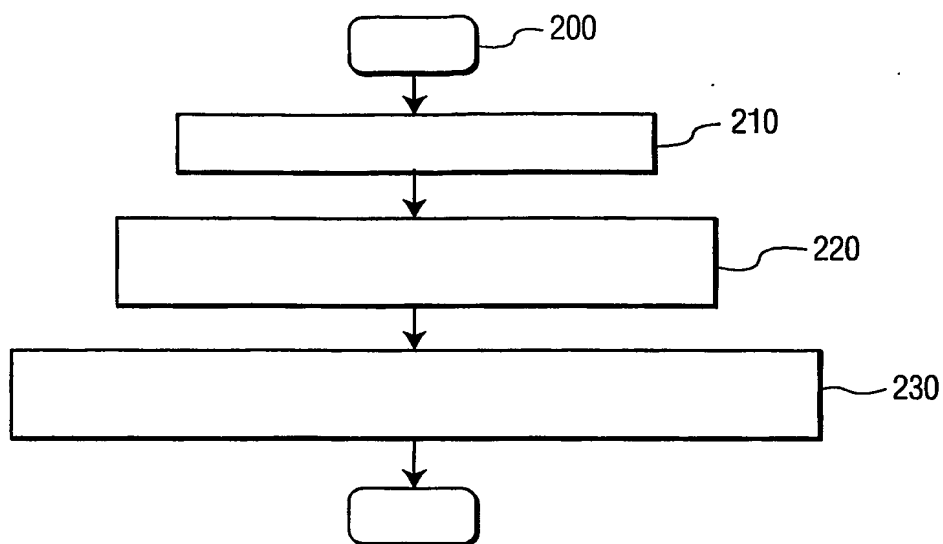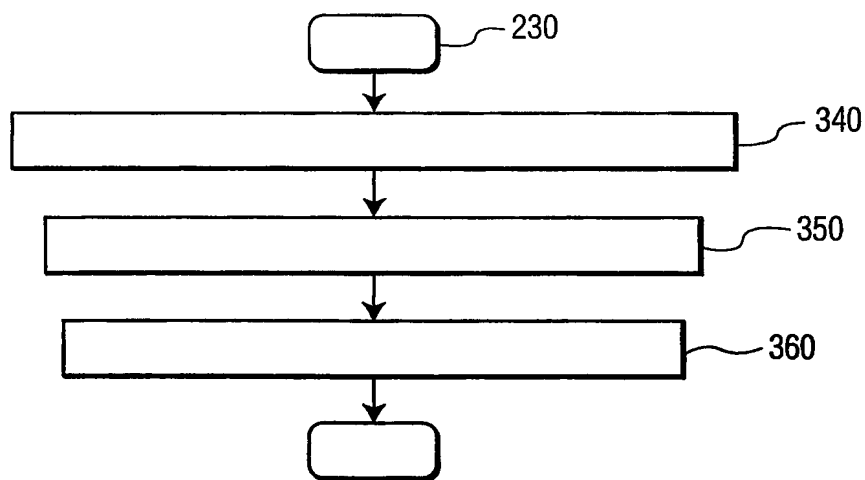
FIG. 1
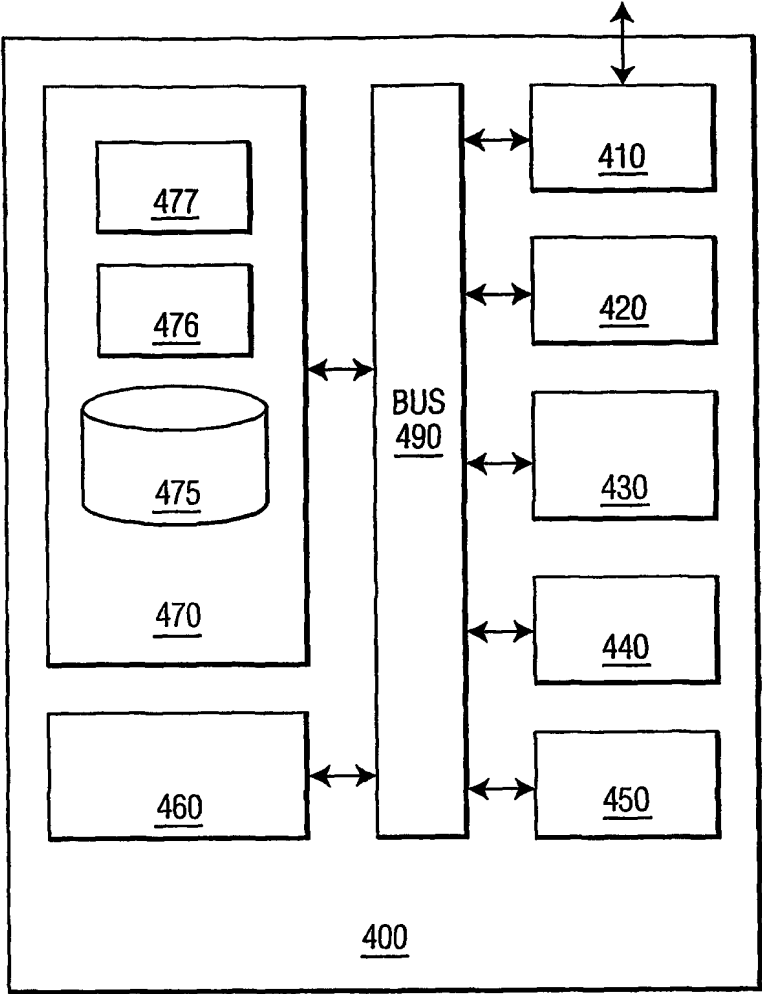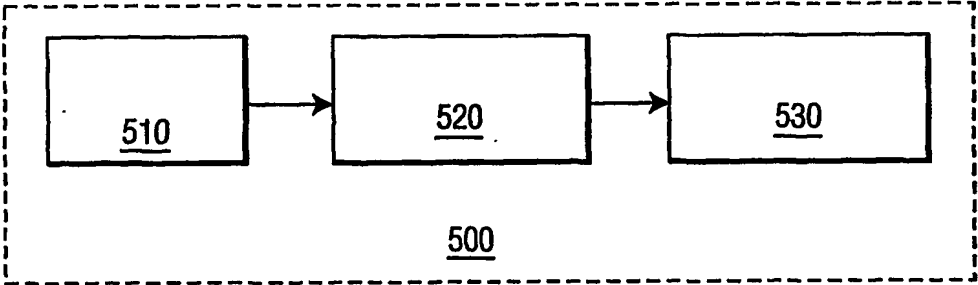
FIG. 2

FIG. 3

FIG. 4

FIG. 5

INTERNATIONAL SEARCH REPORT

PCT/IB 03/05651

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   G01J3/46

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   G01J   G01M   H05B   H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 411 046 B1 (MUTHU SUBRAMANIAN) 25 June 2002 (2002-06-25) abstract	1,9,17
A	EP 0 351 188 A (NIIGATA PREFECTURE) 17 January 1990 (1990-01-17) abstract	1,9,17
A	US 5 844 680 A (SPERLING UWE) 1 December 1998 (1998-12-01) abstract	1,17
A	US 5 677 967 A (E.G.PARISER) 14 October 1997 (1997-10-14) abstract	1,17

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 March 2004	31/03/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	De Buyzer, H

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	SUESSTRUNK S E ET AL: "Chromatic adaptation performance of different RGB sensors" PROC. SPIE - INT. SOC. OPT. ENG. (USA), PROCEEDINGS OF THE SPIE - THE INTERNATIONAL SOCIETY FOR OPTICAL ENGINEERING, 2001, SPIE-INT. SOC. OPT. ENG, USA, vol. 4300, January 2001 (2001-01), pages 172-183, XP002272200 ISSN: 0277-786X the whole document ———	1

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